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Early-Holocene environments in the Wadi Faynan, Jordan

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Abstract: Evidence for early-Holocene environments in the Wadi Faynan in the rift-margin in southern Jordan is described. The early Holocene of Jordan is not well known and palynology, plant macrofossils and molluscs from Wadi Faynan provide evidence for a much more humid _ forest-steppe and steppe _ environment than the present stony desert and highly degraded steppe. The early-Holocene fluvial sediments in the Faynan catchment are predominantly fine-grained, epsilon crossbedded and highly fossiliferous.

They provide convincing evidence for meandering perennial rivers before 6000 cal. BP. It is probable that this early-Holocene landscape was disrupted by the impact of early farmers and by climate change _ the 8.1 ka event appears to be marked by desiccation. By the Chalcolithic, environmental degradation was well advanced.

Key words: Jordan, early Holocene, palynology, vegetation history, palaeoenvironment, early farming, Wadi Faynan.

Introduction

In this paper we describe the early-Holocene riverine deposits of the Wadi Faynan and its tributaries, the Wadis Dana and Ghuweir, in the rift-margin in southern Jordan (Figure 1). The riverine deposits contain pollen, plant macrofossils and molluscs which provide important evidence of the nature of the early-Holocene vegetation and environment in southern Jordan at a time when early farming was beginning to spread through the region. The early Holocene of Jordan is not well known and the Wadi Faynan sequences show significant differences from their better-known equivalents in Israel and further north, such as Lake Hula (Baruch and Bottema, 1999), the Ghab Valley (Yasuda et al., 2000) or the Kopal Basin (Roberts et al., 1999). The data from the Faynan adds considerably to previous accounts of early-Holocene environments in Jordan (Fish, 1989; Rollefson and Simmons, 1985; 1988; Henry, 1986; 1995; Garrard et al., 1986) since it is the first data set from the rift-margin mountains and provides relatively robust evidence for early-Holocene forest. It thus contributes to a growing body of information about climate change and human activity, and their impact in SW Asia.

Early-Holocene vegetation and environment in SW Asia

There is now a considerable amount of information related to early-Holocene vegetation in the northern part of SW Asia, especially Turkey (e.g., Bottema and Woldring, 1984; 1990; van Zeist and Bottema, 1991; Roberts and Wright, 1993; Eastwood et al., 1999; Roberts et al., 1999; 2001), Israel (Baruch and Bottema, 1991; 1999) and Syria (van Zeist and Woldring, 1980; Yasuda et al., 2000). This is largely because of the possibilities for palynology and other techniques offered by high-quality lacustrine sequences in these countries. Early-Holocene vegetation and environments in the southern part of SW Asia are less well known, at least partly because lacustrine sequences there are exceedingly rare (van Zeist and

Bottema, 1991).

The latest Pleistocene throughout SW Asia is characterized by generally dry conditions (e.g., van Zeist and Bottema, 1991; Rossignol-Strick, 1993; 1999; Roberts et al., 2001). At the start of the Holocene, moisture availability generally increased, but the pattern of vegetation development is complex (Roberts et al., 2001). At Ain Ghazal in northern Jordan, oak forest became established in the early Holocene (Rollefson and Simmons, 1985; 1988). In northern Israel, forest expanded in the early Holocene (Baruch and Bottema, 1991). In the Ghab Valley, Syria, human interference seems to have affected vegetation from the start of the Holocene (Yasuda et al., 2000), but sclerophyll woodland became established. In Turkey, moisture availability rose rapidly at the start of the Holocene but total tree pollen expanded relatively slowly in response to vegetation dynamics (Roberts et al., 2001).

In the southern part of SW Asia, the existing records for the early Holocene are largely from archaeological sites (e.g., Fish, 1989; Rollefson and Simmons, 1985; 1988; Henry, 1986; 1995; Garrard et al., 1986). They are thus likely to be discontinuous and to suffer from taphonomic bias. During the early Holocene, presently very arid parts of Saudi Arabia, Jordan and southern Israel experienced relatively moist conditions, with the extension of monsoon rainfall (e.g., Goldberg, 1981; Henry, 1986; 1995; Noy et al., 1980; Schulz and Whitney, 1986; Garrard et al., 1986; Goodfriend, 1991; Bar-Matthews et al., 1997; COHMAP Members, 1988). Thus, at Beidha in the Jordan rift, a diverse steppe was present (Fish, 1989). In the Negev, a sort of forest steppe is supposed to have existed (van Zeist and Bottema, 1991), while there was a denser herbaceous cover than present in interior southern Jordan (Emery-Barbier, 1995) and Saudi Arabia (van Zeist and Bottema, 1991). The data for the early Holocene across this immense area are, however, very sparse and extremely scattered.

Wadi Faynan

The Faynan catchment (Figure 1) drains part of the steep western slope of the Edom mountains on the margins of the Wadi Araba-Jordan Valley Rift. The catchment is steeply sloping, draining Tertiary and Cretaceous limestones overlying Ordovician and Cambrian continental and marginal-marine arenites with thin dolomitic limestones and late-Precambrian syenogranites and ophiolites (Rabb'a, 1994; Barjous, 1992). The Faynan and its tributaries today have a dry desertic climate and are ecotonal between the desert of the Wadi Araba and the residual steppeland of the lower slopes of the Edom mountains. Rainfall in the Wadi Faynan is c. 60mma_1 (Rabb'a, 1994). At high altitude in the mountains, small remnant pockets of degraded juniper-dominated Mediterranean woodland still survive (Ku¨rschner, 1986). In the mountains, rainfall is c. 200mma_1 (Rabb'a, 1994). Rivers in the research area are mostly ephemeral, with prominent braided morphology, though the upper reaches of some are spring-fed and perennial. The area was important from late prehistory to Byzantine times as a major producer of nonferrous metals, principally copper, and has been under intensive multidisciplinary investigation (Barker et al., 1997; 1998; 1999; Pyatt et al., 2000). The present study reports evidence from the river-terrace deposits from the Faynan catchment.

Materials and methods

The survey work on which this account is based was undertaken as part of a multidisciplinary investigation of changing environments and human use of a desert landscape during the later Quaternary. The Quaternary sediments of the Wadi Faynan and its tributaries were mapped from air photographs and a field survey using GPSand barometric altimeters for spatial control. Site codes follow the Faynan Survey numbering system (Barker et al., 1997; 1998; 1999). Sections were photographed, drawn and sampled. Major lithofacies groups were identified from sedimentary structures and sedimentary characteristics in the Quaternary deposits.

A key difficulty with reliance on a single method is the possibility that the signal derived from that technique may be equivocal or misleading for some reason. Multiproxy triangulation for this study has included analysis of lithofacies, sediment characteristics, palynology, molluscs and plant macrofossils, wherever possible.

Palynology has rarely been attempted on arid-zone fluvial sediments, since many have held the misconception that pollen only preserves well in environments where oxidation and microbial attack are limited through waterlogging and=or acidity (e.g., Moore and Webb, 1978). Furthermore, some authorities also question the utility of palynological analysis of fluvial deposits, which are taphonomically complex compared with peat bogs and lakes. Pollen is, however, preserved in a wide variety of arid-zone depositional facies and can be recovered using suitable techniques (Horowitz, 1992). Taphonomic models have been developed to interpret palynological assemblages from fluvial sites (e.g., Fall, 1987). Davies and Fall (2001) describe modern pollen rain on an elevational transect in the rift-margin highlands near the Wadi Faynan. To further address taphonomic problems presented by the present study, samples were taken from a variety of modern depositional facies in the various ecological zones present in and adjacent to the study area. These, in turn, could be linked to available rainfall and temperature records. The detailed results of the taphonomic study are presented in Mohamed (1999). In general,

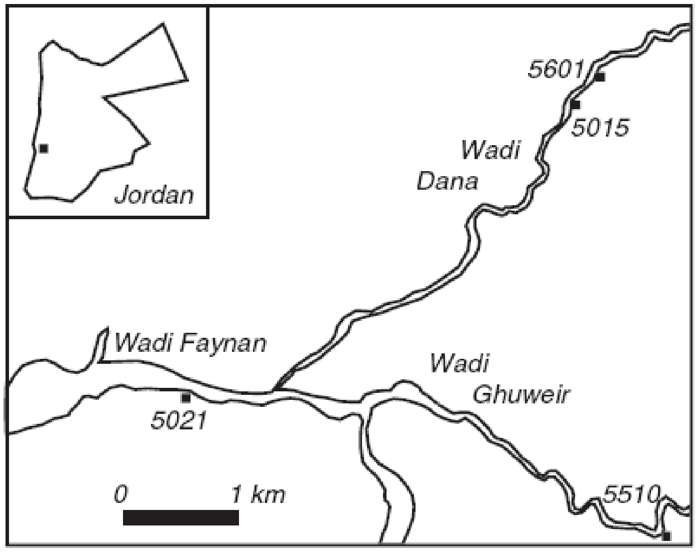

Figure 1 The Faynan catchment, Jordan, and studied sites in the Faynan Member.

The Faynan catchment, Jordan, and studied sites in the Faynan Member.

vegetational types, such as Juniperus woodland, steppe, degraded steppe and steppe-desert, can be recognized from their characteristic pollen signatures in both soils and riverine sediments.

The Wadi Faynan is typical of many arid-zone landscapes, since it does not contain waterlogged or acid sediment sequences. Since traditional pollen extraction methods such as acetolysis are unsuitable for arid-zone sediments (Horowitz, 1992), in this study the 'low-impact' techniques of Hunt (1985) were utilized with reasonable success. Subsamples, usually of 40 g, were disaggregated by boiling in 5% pyrophosphate solution, or, if organic-rich, 10% potassium hydroxide solution.

The resultant suspension was passed through a 150 mm nylon sieve to remove large plant debris and sand grains and then rinsed on nominal 10 mm nylon mesh to remove fines and solutes using a filtered water source. The suspension was swirled on a clock-glass to remove silt and fine sand. The resulting organic concentrate was then stained with safranin and mounted in Aquamount to produce semi-permanent slides, which are lodged in the Geographical Sciences collections at the University of Huddersfield. Exotic 'spikes' were not added because of the low but extremely variable pollen content of the samples. The slides were examined under _400 magnification and counts of over 300 pollen grains were made for each sample, where possible. Pollen sums were calculated using total land pollen, but excluding aquatics, spores, algae and fungal microfossils. Pollen zones were defined visually.

One major problem with palynology is the difficulty of resolving the catchment from which pollen grains are recruited, since many can be carried very long distances by wind. In deserts, large proportions of a total pollen assemblage may be derived from distant vegetation because of low local pollen productivity (Horowitz, 1992). Plant macrofossils are usually considered as auxiliary evidence in a palynological interpretation (Butzer, 1972; Birks and Birks, 2000) but have the advantage of indicating unequivocally the former presence of a plant since they tend to be deposited very close to their source. Similarly, molluscs have limited mobility and durability in fluvial systems and thus provide information about local environments. Plant macrofossils and molluscs were recovered from the sediments, first by extraction of visible material from sections in the field and secondly by wet-sieving 2 kg or larger samples at base camp on 0.5mm stainless steel sieves. Material was air-dried at base camp, then examined and identified at _5_40 magnification on a binocular microscope in the laboratory.

Dating of sedimentary sequences in the arid zone by radiocarbon is difficult because they rarely contain appreciable organic matter. There are also considerable problems with contamination, even of relatively stable materials like charcoal, by younger carbon (M. Bird, personal communication to COH, 2001). In this study, the fluvial sequence at site 5021 interdigitated with archaeological deposits previously dated by Al-Najjar et al. (1990). In situ organic matter from a section excavated back 0.3m at site 5510 was contaminated with modern carbon. Only at site 5015, where a Neolithic site overlies fluvial sediments, was there sufficient organic carbon for a successful radiocarbon date. Relative dating of the sites could, however, be achieved by erection of a local pollen assemblage biostratigraphy (below), which is limited by the extremely low pollen counts. The dating framework for the present study is thus severely limited. For simplicity and better comparability with other radiocarbon data (Heim et al., 1997), the chronology is discussed in uncalibrated radiocarbon years and cal. years BP derived from the CALIB program.

The Faynan Member of the Wadi Faynan

The Holocene deposits of the Wadis Faynan, Dana and Ghuweir are here designated as the Faynan Formation. The type sections for the Faynan Formation lie within the Wadis Faynan, Dana and Ghuweir. Within this formation, four units of member status are recognized here (Table 1). The early-Holocene units are described here as the Faynan Member.

The Faynan Member is composed of bodies of richly fossiliferous silt, sand and gravel, often with clear epsilon crossbedding, overlying bedrock or older gravels of Pleistocene age. Its top surface is a noticeable and distinctive terrace feature, between 2 and 10m above the present active wadi floors, except where it is overlain by more recent fan deposits. Following a phase of substantial incision, the coarse sandy gravel of the Dana Wadi Member, of later-Holocene age, aggraded at lower altitude (Mohamed, 1999). In this account, sediments of the Faynan Member are described in detail from site 5021 in the Wadi Faynan, sites 5015=5500 and 5601b in the Wadi Dana and site 5510 in the Wadi Ghuweir.

Stratigraphy and sediments

The predominant characteristic of the Faynan Member is the

presence of epsilon crossbedded, relatively fine-grained, wellsorted and richly fossiliferous sediment. This contrasts markedly with the trough crossbedded, gravel-grade and generally unfossiliferous sediments of other Pleistocene and late-Holocene terrace-deposits of the Faynan catchment.
Site 5021 (Figure 2) consists of 1.5m of epsilon crossbedded pale grey silts, stony silty diamicts and ash beds all with much ash, charcoal, bone and potsherds. Traces of reed rhizomes and desiccation cracks occur in a few levels. The deposits infill a small channel incised into Pleistocene gravels. The channel fills are overlain by c. 1.2_1.6m of aeolian silt of the Tell Loam Member.
Table 1

Site 5015=5500 lies on a fluvially cut surface eroded across Pre-Cambrian Fidan Syenogranite. The stratigraphy of the site is complex (Figure 2). On the rock surface is an epsilon crossbedded unit of 1.6m of light brown fine shelly gravels with a lens of mid-grey ashy sand. This passes upward into 0.4m of pale yellow-brown massive sand with shelly lenses at the base. These are overlain by 0.5m of massive ashy silt with occasional lithic artifacts and potsherds, which in turn is overlain by 0.7m of massive light brown silt. The silts are cut by a scour containing 1.5m of coarse epsilon crossbedded gravel overlain by up to 0.5m of massive silty sand, on which is developed a clayenriched palaeosol 0.2m thick containing calcified root tubules, ash and occasional Neolithic artifacts. A number of ashy pit-fills were cut in the palaeosol. The whole site is overlain by crudely bedded stony and silty colluvium up to 1.6m thick.
At site 5601b, the Faynan Member occupies a channel incised into coarse Pleistocene gravels. The channel-fill consists of a basal 0.2m of imbricated clast-supported fine gravel, overlain by up to 0.9m of pale yellow-brown plane-bedded fine shelly sands (Figure 2). These are unconformably overlain by up to 0.3m of red-brown trough crossbedded coarse sand, with abundant shells in the basal few centimetres.
At site 5510, the deposits of the Faynan Member occupy a channel incised into coarse unfossiliferous gravels of probable late-Pleistocene age. The basal unit of the Faynan Member is an epsilon crossbedded fining-upward sequence 1.2m thick of very fine gravel passing upwards into whitish silts and then pale grey clays with abundant impressions of Typha and Phragmites leaves and stems (Figure 2). These fine-grained deposits are strongly contorted, possibly by load casting. They are unconformably overlain by up to 6m of trough crossbedded sands, silts and fine gravels. The deposits are overlain unconformably by up to 14m of alluvial fan sediments of the late-Holocene Wadi Dana Member.

Palynology

The pollen assemblages from the Faynan Member can be divided, tentatively, into three local assemblage-biozones, which can be recognized at most of the studied sections. These appear to be chronologically and stratigraphically distinct within the limited area of the Faynan catchment.
Poaceae-Ostrya carpinifolia-Pinus assemblage-biozone (POP)
This assemblage biozone is defined by the usually high occurrence of Poaceae (16_32%), Pinus (5_70%), Ostrya carpinifolia (4_32%), Plantago (4_20%) and sometimes high Liliaceae (4_18%), Juniperus (0_15%) and Artemisia (0_15%).
Characteristic
species often present include Quercus (0_4%), Ulmus (0.5_2.5%) and Caryophyllaceae (0_2%). Other taxa, e.g., Rumex (0_1%), Hippophae, Potentilla (0_0.5%), Pistacia (0_0.5%), Malva (0_1.5%), Cyperaceae (0_2%), Centaurea (0_1.0%) and Helianthemum (0_0.5%) are occasionally present. The end of this biozone is defined on the decline of Ostrya carpinifolia, a slight decline of Pinus and Poaceae and the disappearance of Ulmus.
The type locality for this biozone is the basal 1.5m of site 5510 in the Wadi Ghuweir (Figure 3). The POP assemblagebiozone
can also be recognized in the basal part of site 5015=5500 in the Wadi Dana (Figure 4).
Poaceae-Pinus-Artemisia assemblage-biozone (PPA)
This assemblage-biozone is defined by high Poaceae (10_38%), Pinus (7_19%) and Artemisia (12_18%), a moderate amount of Plantago (3_11%) and variable Chenopodiaceae (4_35%). Often present are Ostrya carpinifolia (0_2%), Quercus (0_2%), Rhamnus (0_3%), Juniperus (0_7%), Olea (0_3%), Caryophyllaceae (1_16%), Liliaceae (0_4%) and Cerealia-type pollen (0_2%). Other species, sometimes present, include Acer (0_2%), Balanites (0_1%) and Ephedra (0_4%).

Table 1 Units of member status in the Faynan Formation (*type section)

Member	Lithology	Sites	Date
Khirbet Member	Massive or laminated sandy lacustrine silts	5017*	Late Holocene
		5051	
		5518	
Tell Loam Member	Laminated silts with calc nodules	5022	Mid- to late Holocene
Wadi Dana Member	Trough crossbedded sandy gravels	5025	Late Holocene
		5509	
		5520*	
		5510 (top)	
Faynan Member	Epsilon crossbedded silts and sandy gravels	5510 (base)	Early Holocene
		5500/5015	
		5021*	

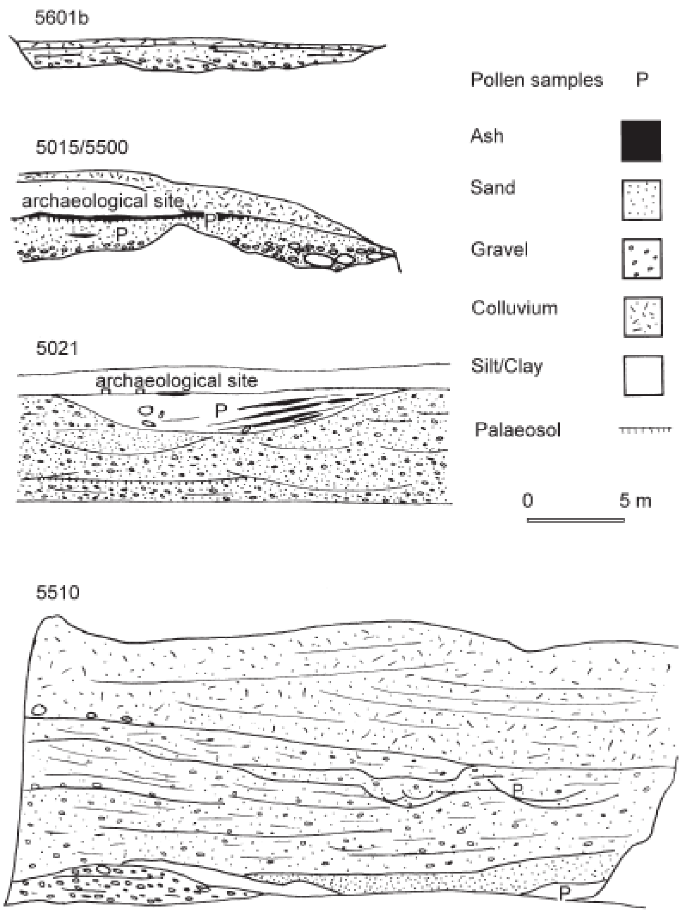

Figure 2 Stratigraphy of selected sites in the Faynan Member.

The base of this assemblage-biozone is defined by the top of the preceding POP biozone. The top of this biozone is defined by the disappearance of Ostrya carpinifolia, Pistacia, Quercus and Rhamnus. The type locality for this assemblage biozone is the palaeosol at the top of the fluvial sequence at site 5015 in the Wadi Dana (Figure 4). The assemblage-biozone can also be recognized in the basal part of site 5021 in the Wadi Faynan (Figure 5).

Poaceae-Artemisia-Plantago assemblage-biozone (PAP)

The base of this assemblage-biozone is defined at the top of the preceding (PPA) assemblage-biozone. This assemblagebiozone is defined by high Poaceae (22_28%), Pinus (5_14%) and moderate Artemisia (3_5%), Plantago (5_7%), Liliaceae (3_6%), Chenopodiaceae (5_9%) and Lactuceae (5_7%). Other species that are sometimes present include Juniperus (0_2%), Cupressaceae (0_2%), Pistacia (0_2%) and Ericaceae (0_1.5%). Cultivated species are also present occasionally, including Cerealia-type pollen (0_5%).

The type locality for this assemblage-biozone is site 5510 in the Wadi Ghuweir (Figure 3) and it is also recognized at site 5021 in the Wadi Faynan (Figure 5).

Plant macrofossils

Rhizomes of Phragmites were found in the silty channel-fill at site 5021. Impressions of stems and leaves of Typha and Phragmites were common in the basal clay unit at site 5510. Poorly preserved plant macrofossils were also recovered from this unit. The identifications are listed in Table 2.

Molluscs

Abundant unrolled shells of Melanopsis praemorsa (Linnaeus) were recovered from the basal gravels and sands at site 5015=5500 and the plane-bedded sands and the base of the trough crossbedded sands at 5601b. Three specimens of M. praemorsa were found by sieving 20 kg of the basal part of the silty channel-fill at site 5021. One specimen of Lymnaea sp. was found in the massive sand below the palaeosol at site 5015. Two specimens of Theba sp. were recovered from the massive sand below the palaeosol at site 5015 and one specimen was found in the plane-bedded sands at site 5601b.

Melanopsis praemorsa is indicative of clear perennial running fresh water (Pfleger and Chatfield, 1983). Lymnaea is also aquatic, but less demanding in its requirements. Together, they point to perennial running water at these sites. The genus Theba is today associated with relatively dense steppic vegetation in the research area (field observation by COH and HAE, 1998).

Diatoms

Analysis of samples from silty channel-fill units at site 5021 revealed the presence of poorly preserved frustules of the diatom Navicula. In this desertic context Navicula spp. must be considered to be aquatic.

Dating

Calibrated ages are shown as the 2r range flanking intercepts, since two or more intercepts are possible with most of these dates. A sample of oak leaves was submitted for accelerator radiocarbon dating from the basal clays of site 5510. The sample was heavily contaminated with modern carbon (probably through micro-infestation) and was undatable (Beta-119601).

A pit-fill in the palaeosol overlying the fluvial units at site 5015=5500 has been dated to uncal. 7240 _ 90 BP (8276 [8105, 8099, 8025] 7868 cal. BP) (Beta-111121).

The deposits of site 5021 infill a small channel incised into Pleistocene gravels, provisionally dated by OSL to approximately 45 900 BP (G. Duller, personal communication to DG, 1998). Al-Najjar et al. (1990) secured radiocarbon dates of 6410 _ 115 uncal. BP (7563 [7405, 7403, 7318] 7062 cal. BP) (HD 10567) and 6360 _ 45 uncal. BP (7418 [7269] 7164 cal. BP) (HD 12335), from the base of the archaeological site, which interdigitates with the channel-fill deposits and the base of the PAP biozone. A date, higher in the archaeological site, of 5740 _ 35 uncal. BP (6654 [6499] 6412 cal. BP) (HD 12337), in aeolian sediments, postdates the end of fluvial sedimentation at the site and the effective end of the PAP biozone.

A further date of 5375 _ 30 uncal. BP (6278 [6191] 5999 cal. BP) (HD 12336) was obtained from 1.05m from the surface

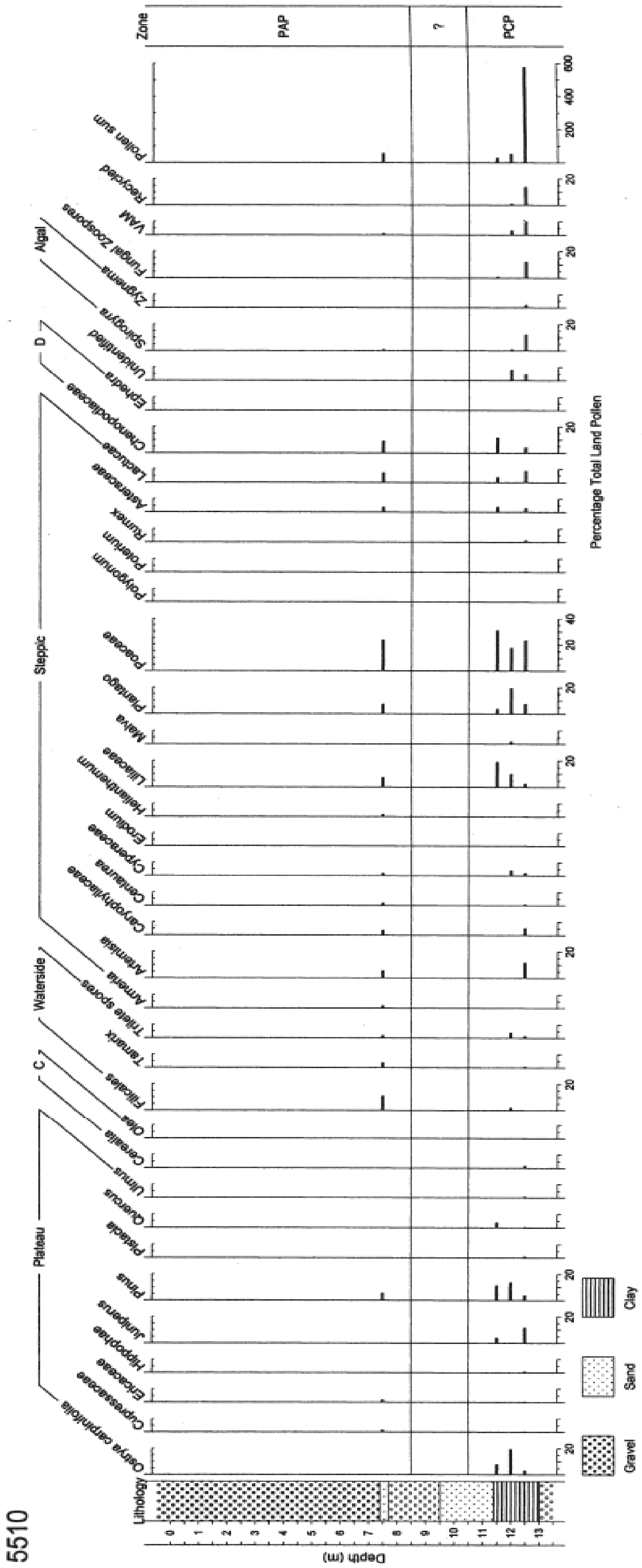

Figure 3 Pollen diagram for site 5510 in the Wadi Ghuweir.

of the aeolian sediments (Al-Najjar et al., 1990).

Early-Holocene floras

It must be pointed out that much of the following discussion relies on rather small pollen assemblages, although these are consistent with the other lines of evidence adduced. As a pollen assemblage from a particular time and place is a function of the regional flora and vegetation, which are significantly influenced
by regional climates, there has to be a relationship between ancient pollen assemblages and past climates. This relationship is complex and the business of extracting information about past climates from the pollen is not simple, especially in times of significant human impact on the landscape (cf. Carrion et al., 2001). It is apparent that shortterm climatic fluctuations do not always register in the pollen record (e.g., Lamb et al., 1995). Nevertheless, the palynological
Figure 3 Pollen diagram for site 5510 in the Wadi Ghuweir.
approach has proved to be one of the major tools with which changes in vegetation may be traced and past climate reconstructed.
In this case, the present-day analogues in Table 3 provide some calibration for the pollen record.
POP biozone
The relatively high counts for tree pollen in the POP biozone are dissimilar to the recorded assemblages from all modern vegetation types locally _ or now present in the southern part of SW Asia (Mohamed, 1999). The modern plateau flora locally still has relict stands of Juniperus and Pinus. Ulmus is, however, completely absent from the region and, in the absence of macrofossil evidence, its position in the landscape is uncertain. Ostrya carpinifolia, Olea and Quercus are present today (or were, in the recent past) in wetter parts of SW Asia (for instance, northern Israel, Lebanon, parts of Syria, Iran and Turkey) and they, especially the latter two, are part of the modern pollen rain locally (Davies and Fall, 2001; Mohamed, 1999). In interior southern Jordan in the early Holocene, Emery-Barbier (1995) reported fair amounts of Ulmus, Ostrya and Betulaceae. It is possible that these species were part of a richer former plateau flora in the region and=or that they may have been living in sheltered valley-floor sites adjacent to springs and standing water, alongside other waterside taxa such as ferns and Tamarix. Macrofossils of Quercus and Olea from site 5510 are perhaps consistent with these species living close to the watercourses.
The high counts for Poaceae, Plantago and other herbaceous species such as Artemisia, Malva, Rumex, Cyperaceae, Centaurea and Helianthemum in the POP biozone are characteristic of steppic landscapes (Mohamed, 1999; Bottema and Barkoudah, 1979). Comparisons may be made with spectra in Davies and Fall’s (2001) altitudinal zone 2b (currently around 1000_1100m a.s.l.). A position near the forest-steppe ecotone may therefore be argued for the POP biozone. The presence of occasional Cerealia-type pollen may be consistent with the activities of early farmers or may simply reflect the

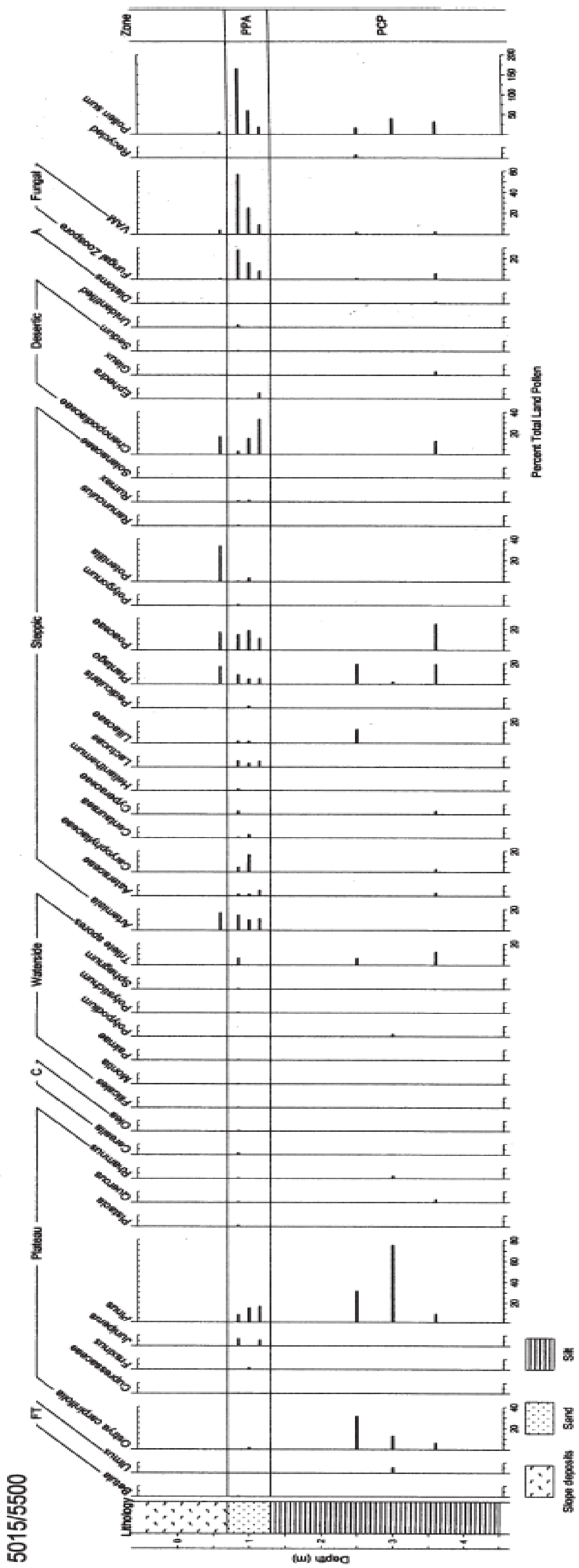

Figure 4 Pollen diagram for site 5015/5500 in the Wadi Dana.

wild cereals that grow naturally in the area. This flora predates the radiocarbon date of 7240 _ 90 uncal. BP (8276 [8105, 8099, 8025] 7868 cal. BP) (Beta-111121) at site 5015 by an unknown period of time, but is unlikely to be older than early Holocene. Thus, before c. 8.0 ka, the POP pollen assemblage is characterized by high tree pollen and high Poaceae, Artemisia, Plantago and pollen of other steppic herbs. The study area thus probably lay just outside the margin of the Mediterranean forest zone, and the vegetation was probably steppe plus waterside trees. The precipitation therefore was probably a little less than at Tafila, which lies just inside the forest margin (Table 3), so may be around 200mma_1.

PPA biozone

The high incidences of Poaceae and Artemisia, together with moderate Plantago and the frequent occurrence of Caryophyllaceae,
Liliaceae and other typically steppic species in the PPA biozone is consistent with a predominantly steppeland landscape (e.g., Davies and Fall, 2001; Bottema and Barkoudah, 1979). Again, comparison may be made with Davies and Fall's (2001) altitudinal zone 2b. The terrestrial mollusc Theba sp., found at site 5015, is today associated with relatively dense steppic vegetation in the research area (field observation by COH and HAM, 1998).

The high counts for Pinus and frequent occurrence of Juniperus, Ostrya carpinifolia, Olea and Quercus in the PPA biozone suggest the presence of limited Mediterranean woodland of modern type. Waterside plants such as the ferns,
Figure 4 Pollen diagram for site 5015=5500 in the Wadi Dana.
palms and Balanites suggest at least occasional moisture-demanding vegetation on the wadi floors. The rise of Chenopodiaceae
and Ephedra suggests areas of very dry, possibly disturbed ground. The disturbance of the landscape may have been partly anthropogenic _ Cerealia-type pollen in this biozone is perhaps consistent with the activities of early farmers, though it may also indicate wild cereals. The ashy deposits and pitfills at site 5015 are strong evidence that Neolithic people were using the area at this time.

The PPA assemblage-biozone has been dated to 7240 _ 90 uncal. BP (8276 [8105, 8099, 8025] 7868 cal. BP) (Beta-111121) at site 5015. This is consistent with the Neolithic artifacts at this site. At site 5021, the top of the biozone lies with 14C dates of 6410 _ 115 uncal. BP (7563 [7405, 7403, 7318] 7062 cal. BP) (HD 10567) (Al-Najjar, 1990).

Thus, the PPA biozone between 8.0 and 7.4 ka is characterized by a decline of Ostrya, disappearance of Ulmus, and the rise of Chenopodiaceae, Ephedra and Artemisia. Through reference
to Table 3 it appears that the precipitation was certainly less than modern rainfall at Tafila but more than that at Wadi Faynan today, so a rough rainfall estimation can be made at c. 150mma_1. The beginning of this desiccation event coincides with the global 8.1 ka event (e.g., Leira and Santos, 2002).

PAP biozone

High Poaceae, moderate Plantago and Artemisia are an indication

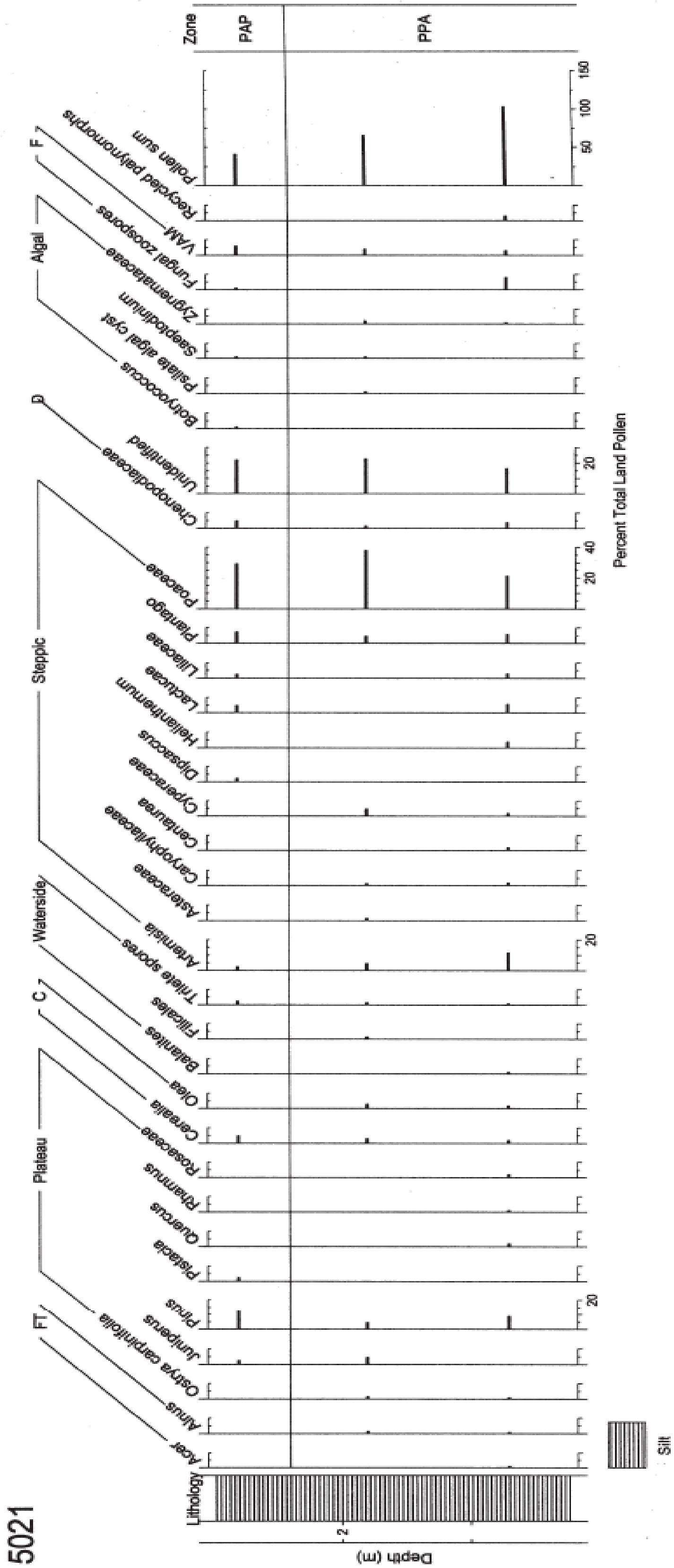

Figure 5 Pollen diagram for site 5021 in the Wadi Faynan.

Table 2 Plant macrofossils from site 5510

Macrofossils	Number
Quercus ilex (leaf)	6
Olea sp. (wild) (stone)	2
Cupressus sp. (leaf)	1
Caryophyllaceae (achene)	1
Chenopodiaceae (achene)	1
Poaceae (seed)	3
Cyperaceae (nutlet)	3
Hippuris sp. (stone)	1

Table 3 Some present-day vegetation analogues*

Area	Amount of rainfall/year (mm)	Vegetation
Shobak	315	Broadleaved woodland (oak)
Tafila	250	Broadleaved woodland (oak)
Wadi Faynan	*c.* 100	Very poor steppe
Safi	70	Salt desert
W. Araba/Aqaba	30	Acacia scrub/desert

*Sources: *Jordan climatological data handbook* (1988), Kürschner (1986), Tariq (personal communication, 1998).

of a steppic environment in the PAP biozone, but one
with fewer signs of disturbance and drought than the preceding
biozone. Again, comparison can be made with Davies
and Fall's (2001) altitudinal zone 2b. Some waterside vegetation,
including Pistacia, and some plateau flora, including
Pinus and Juniperus, existed, so this flora was much like the
modern one in aspect, although significantly less degraded.
The flora differs significantly from that of the previous biozones
in that the diversity of tree pollen had fallen. The plateau
flora, although most probably more widespread than present,
was nevertheless modern in aspect, being dominated by pine
Figure 5 Pollen diagram for site 5021 in the Wadi Faynan. and
juniper, by the start of this assemblage-biozone.
The base of the PAP assemblage-biozone has been dated to
6410 _ 115 cal. BP (7563 [7405, 7403, 7318] 7062 cal. BP) (HD
10567) (Al-Najjar et al., 1990). At the top of 5021 is a date
of 5740 _ 35 cal. BP (6654 [6499] 6412 cal. BP) (HD 12337)
(Al-Najjar et al., 1990).
Thus, indicators of severe dessication, particularly the
Chenopodiaceae
and Ephedra, decline in the PAP biozone, but
trees continue to decline. We hypothesize that regional rainfall
recovered somewhat, but human impact, possibly grazing
pressure from neolithic herders, prevented the regeneration
of trees.

The later Holocene

Substantially different pollen assemblages are associated with
the Chalcolithic=early Bronze Age site 5051 (Barker et al.,

1998). At this site, tree pollen is virtually absent and, although a grass-dominated steppe assemblage was present, there were clear signs, from very high counts of vesicular arbuscular mycorrhyza (VAMs), of eroding soils.

Regional comparisons

In eastern North Africa, several lines of evidence show that areas currently occupied by hot desert were relatively cool and moist during the earlier Holocene (10 000 to c. 4000 BP: Gasse, 2000). A stronger monsoonal circulation and a northward shift of tropical convectional rain brought much more moisture to the Sahara, Arabia and northwest India than it does now (Whyte, 1995; COHMAP Members, 1988). As a result, much of the Sahara was savanna grassland rather than desert (Fontes and Gasse, 1991) and this pattern extended into Jordan (Fish, 1989; Kohler-Rollefson and Rollefson, 1990; Emery-Barbier, 1995) and Israel (e.g., Goldberg, 1981; Goodfriend,
1991; Frumkin et al., 1991; Bar-Matthews et al., 1997).
The present study shows that this climate and vegetation pattern also occurred in SW Jordan, with higher rainfall and vegetation in some ways analogous to the modern flora around 800 m higher in the rift-edge mountains than present at low altitude. This contrasts with the situation in the western Mediterranean,
which was dryer during the early Holocene, but became more humid during the mid-Holocene (Carrion et al., 2001; Cheddadi et al., 1998). The late appearance of a forest cover in parts of Turkey has also been attributed to aridity (Roberts and Wright, 1993), although the situation there may be more complex than simple aridity (Eastwood et al., 1999; Roberts et al., 2001).

Fluvial environments

At site 5510, the silt-filled meander plug indicates initial sedimentation by a meandering stream. Epsilon crossbedded fine gravels and sands show that significant aggradation by meandering streams took place at site 5500=5015, before 8.0 ka. The epsilon crossbedded silty gravels and channel fill show that similar sedimentation by meandering streams occurred at site 5021 until c. 7.4 ka. There is good evidence for perennial water. In particular, Melanopsis praemorsa is indicative of clear perennial running fresh water (Pfleger and Chatfield, 1983) and is today limited to perennially flowing streams in the area.

The picture of meandering sedimentation is not, however, simple. At site 5510, meandering sedimentation was replaced by braided aggradation, with pollen biostratigraphical correlation with site 5021 suggesting that trough crossbedded sands, silts and gravels accumulated until c. 6.4 ka. There was thus a pattern of localized aggradation in the tributary wadis in the early Holocene, but not extending downslope into the Wadi Faynan to any significant extent that can now be detected.

In the Wadi Dana, aggradation seems to have been in a meandering river, a distinctly unusual phenomenon in the Quaternary where most meandering rivers have incised or been stable. Barker and Hunt (1995) document an aggrading meandering river with high sediment supply but constraint by abundant bankside vegetation, and this may have been the case in the Wadi Dana. In the Wadi Ghuweir aggradation was braided after an initial meandering stage. Possibly sediment supply in the Ghuweir was sufficiently high to force a localized transition to braiding (Schumm, 1979), especially where large tributaries entered the wadi, as at site 5510. The causes of this change to braiding are uncertain, and might be one of the following.

Tectonic impacts as demonstrated in the Dead Sea region by Frostick and Reid (1989) and in Israel by Porat et al. (1997) are unlikely because the alluvial geometry, with the depositional wedge thinning rapidly downstream, is not likely to have resulted from tectonic displacement along the rift-margin faults. The major rift-margin faults are all downstream of the sediment aggradation discussed here.

Mining, which can lead to alluviation (Macklin and Lewin, 1986), is unlikely because of the early date and the low level of metal contamination in samples from sites 5015=5500 and 5021 (F.B. Pyatt, D.D. Gilbertson and J. Grattan, unpublished data, 1998).

Landsliding might be a possible cause. A slow landslide would supply much debris to the wadi and perhaps induce braiding downstream, but the bedrock is syenogranite, basalt and sandstone in this part of the catchment. There are no clay layers or shale to work as a lubricant surface and there is no morphological evidence for large-scale landsliding on the aerial photography.

Agricultural activity is perhaps the most likely hypothesis for the cause of this episode of alluviation. Cereal pollen has not been recovered from the aggraded sediments in any quantity, so the impact of grazing by sheep and goats on the steep hillsides of the Wadis Ghuweir and Dana is perhaps the most likely cause. VAMs are symbiotic on the roots of plants and are thus unlikely to be present in fluvial sediment unless liberated by soil erosion. At site 5016 in the Wadi Dana, a thick loess deposit of Lateglacial age was found beneath stony colluvium. Loess is very erodible and would have been extremely vulnerable to erosion once livestock had removed the vegetation cover. This would have given a rapid initial pulse of sedimentation with the first intensive grazing of the area. Sheep and goats are reported at the nearby Neolithic site at Beidha from 8500 BP (Harris, 1996) and have been found in early-Neolithic sites in the adjacent Wadi Fidan (Richardson, 1997). Furthermore, by the beginning of the seventh millennium, goat herding was widely practised throughout southern SW Asia (Kohler-Rollefson and Rollefson, 1990). Sediment supply changes as the result of human activity are thus the most likely reason for aggradation in the Wadi Dana and the change to braided aggradation in the Wadi Ghuweir.

Conclusion

This study provides important evidence for early-Holocene vegetation and climate in the rift margin of southern Jordan. A steppic environment at the margins of a type of Mediterranean forest characterized by hop-hornbeam, oak, pine, juniper, olive, cypress and elm are indicated. This is a much more biodiverse forest than is now present in the southern Jordanian mountains. Similar, but depleted, vegetation to that present in the early Holocene in the Wadi Faynan now occurs only around 800 m higher in the rift-margin mountains. Molluscan evidence suggests that rivers which are now ephemeral were then perennial.

Before 8.0 ka, rainfall of about 200mma_1 is suggested by analogy with modern vegetation and rainfall patterns. There is evidence for decreasing rainfall at 8.0 ka coinciding with changing global temperatures. After 7.4 ka, rainfall seems to have increased, but trees did not regenerate. By the Chalcolithic, the area was virtually treeless. It is hypothesized that grazing pressure was responsible for the inhibition of regeneration of the tree flora.

From the studies of the vegetational and alluviation history presented above, the early-Holocene alluviation in the Wadi Faynan catchment may coincide with early arable agriculture and herding. It has no strong association with climatic causes in this area. Evidence from the Wadi Faynan suggests that in the early Holocene fluvial aggradation occurred during the generalized transition from Mediterranean to steppic environments and climate. It is possible that desiccation was the proximate cause of alluviation, but aridification does not seem to have been severe. The breakdown of vegetation and liberation of sediment in this environment is likely to relate to anthropogenic activity rather than climate per se.

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